Eastonian (Upper Ordovician) Graptolites from Michelago, near Canberra

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A diverse Upper Ordovician (Eastonian) graptoloid fauna of some 20 taxa has been obtained from 'black shales' of the uppermost Foxlow Beds near Ryrie Hill south of Michelago. Eighteen of these are figured and described. The age indication is Eastonian 2 and 3, possibly about the *caudatus/morrisi* Biozone boundary in global graptolite terms. Some specimens exhibit a peculiar preservation, possibly of associated soft parts, though not necessarily graptolite soft parts.

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INTRODUCTION

Ordovician graptolites have been known for a number of years from the black shales towards the top of the Foxlow Beds. Richardson (1979) gives a detailed account of past work, beginning with the recognition of the Foxlow Beds by Oldershaw (1965) and records Ordovician graptolites from two locations west of the Ryrie trigonometrical station (appendix 1, pp 182-183). Richardson and Sherwin (1975) discuss the Silurian outcrop slightly further west (Fig. 1). The present collections were made from the quarry east of the Ryrie trigonometrical station (Michelago 1:100,000 map sheet 8726: 96953825, Fig. 1). The Ordovician forms recorded by Richardson (1979) are *Orthograptus* and *Climacograptus* species in open nomenclature, a possible amplexograptid, leptograptids and *Dicellograptus forchammeri* (sic) *flexuosus*. Richardson (1979, p.30) notes that the graptolites represent "various zones within the Eastonian. Some possible late Gisbornian and early Bolindian fossils are also present." Our work entirely accords with this (Table 1), although we have recorded 20 taxa with just one in open nomenclature: these are, for the most part, illustrated and described below.

Our collections were made in 2002 by P.L.W. In addition to the interestingly diverse fauna, embracing seven genera, some of the specimens exhibit a peculiar structure associated with parts of the rhabdosome of some biserials. It is possible that this represents soft tissue of some kind and it is illustrated and discussed in more detail below.

PRESERVATION: GENERAL

The graptolites are found in what was once black shale but which is mostly deeply weathered buff or whitish, soft mudstone: even traces of the original hemipelagic laminae are muted. The rock splits readily along the bedding planes and, except where stained with hematite, the graptolites are inconspicuous and in places very faint. A little of the original periderm is left in some instances but clay mineral replacement may also have occurred. In the few areas where the original black shale is preserved, in blobs and patches, the graptolites are dark silver-grey on a dark background, and are poorly preserved. The most serious drawback to this preservation is recognition of proximal end features, especially of proximal spines and early thecal growth. Even identification of early thecal apertures is often difficult. On the positive side there is no tectonic deformation: slabs with variously-orientated graptolites show no stretching, and there is no tectonic lineation on the bedding surfaces. Equally, there is no tectonic flattening parallel to the bedding, at least not to an extent that alters the dimensions of the graptolites. All the specimens are more or less

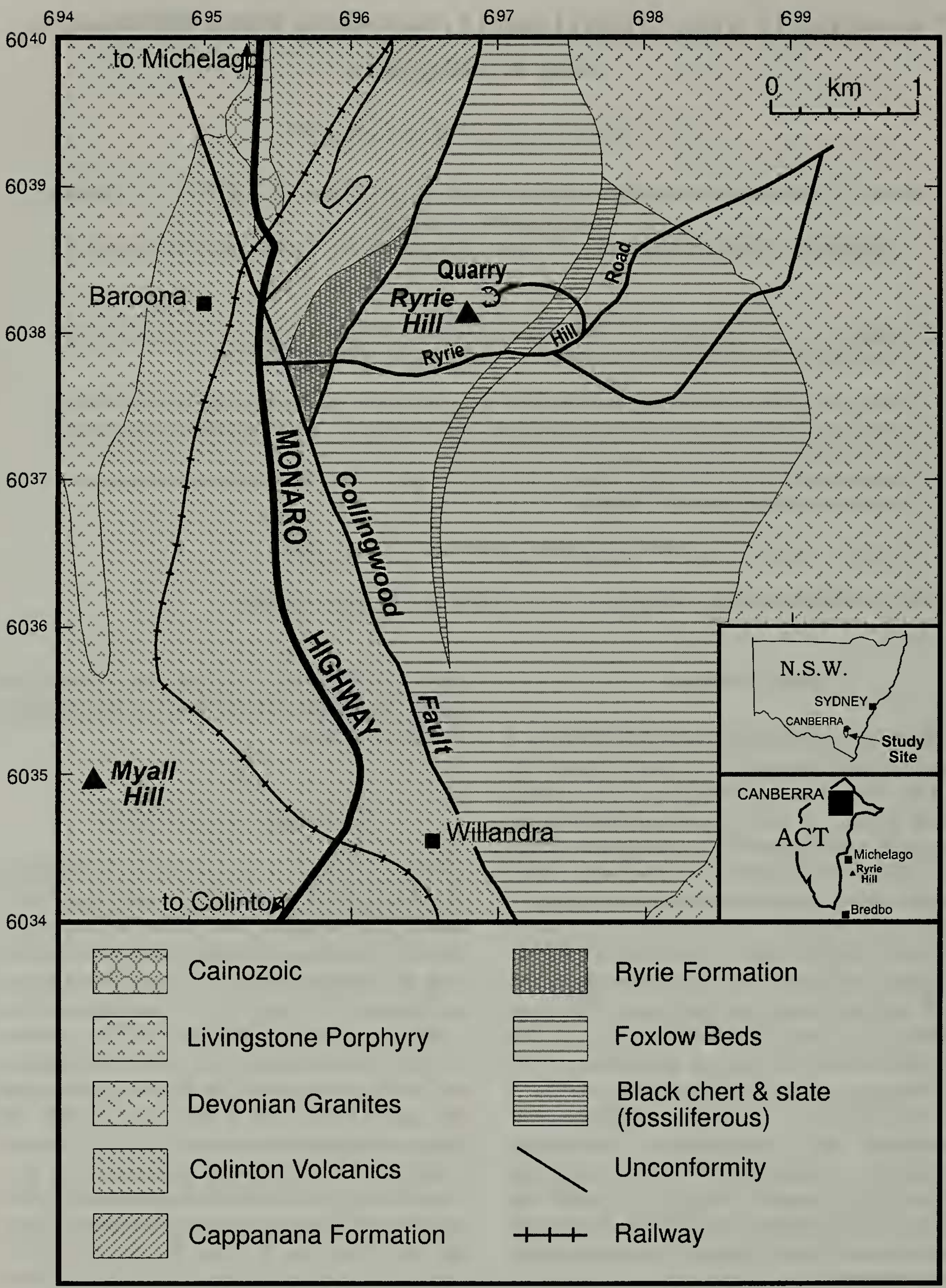

Figure 1. Location of the quarry at Ryrie Hill, south of Michelago and Canberra. Topography based on 1:100,000 Topographic Sheet 8726 Michelago 1974 Edition 1, generalised geology after Richardson & Barron 1977.

Table 1. Global ranges of the Michelago faunal elements plotted against Australian stages and a set of widely-recognised global biozones. Asterisks = not figured or described in this paper; circles indicate where an Australian range differs slightly from other records.

		clingani					
"Global" biozones	gracilis	multidens	caudatus		morrisi/	complanatus	?preanceps
		peltifer	wilsoni		linearis		
Australian Stages	Gisbornian 1	Gisbornian2	Eastonian 1	Eastonian 2	Eastonian 3	Eastonian 4	Bolindian 1
?*Climacograptus uncinatus*							●
Climacograptus mohawkensis				●	● ●		
?*Climacograptus lanceolatus*			●				
?*Climacograptus spiniferus*				●	● ●	●	
Climacograptus tubuliferus				●	● ●	●	●
Climacograptus caudatus		●	●	●			
Orthograptus a. pauperatus			?	●	● ●		
Orthograptus a. intermedius		●	●				
Orthograptus c. calcaratus		●	●	●	● ●		
Orthograptus c. cf. vulgatus			●	●	● ●		
Orthograptus c. aff tenuicornis		●	●	●			
Orthograptus c. ?priscus	●						
Orthograptus q. quadrimucronatus			○	●	● ●		○
Glyptograptus davesi				●	●		
*Plegmatograptus? nebula**			●	●	● ●		
Leptograptus flaccidus cf. macer				●	● ●		
Leptograptus flaccidus spinifer			●	●	● ●		
Dicellograptus morrisi				●	● ●		
Dicellograptus cf. caduceus				●	○	○	
*Cryptograptus spp.?**	●	●	●	●	● ●		

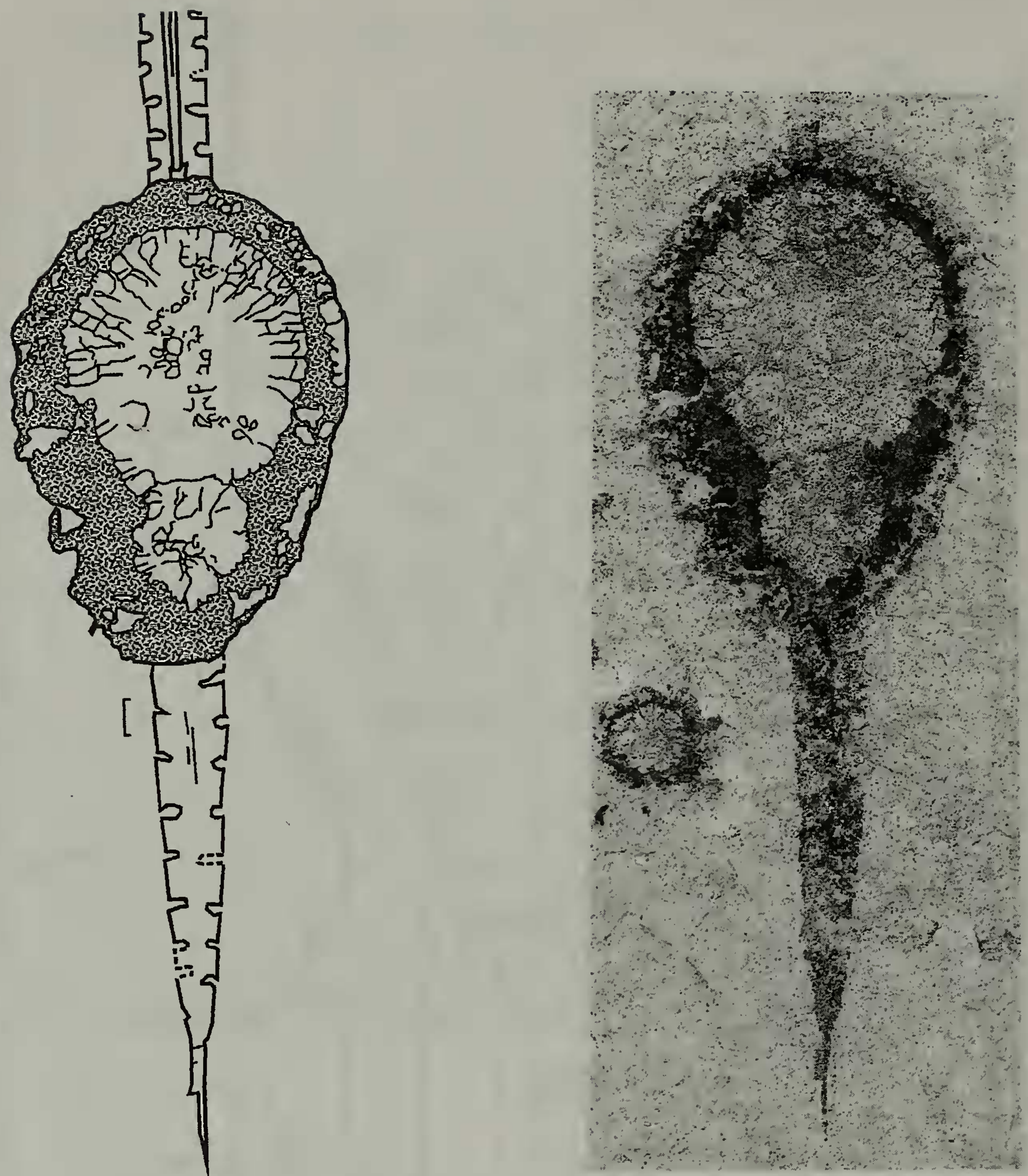

Figure 2a (left) *Climacograptus caudatus* Lapworth, AMF 114974, sketch of specimen showing possible soft tissue preservation, (full explanation in text); b (right) original of the same specimen as in 2a for comparison with interpretation, scale bar 1 mm.

diagenetically flattened and there is little pyritisation in the black shale, which is unusual. A number of specimens show what may be a thick layer of chloritic material entombing them, though this cannot be related to any tectonic strain shadow, at least in the outcrops we have dealt with. There is, however, a great deal of secondary hematite along veins, joints and as patches and circular blobs on the bedding planes: in places the whole rock is suffused with a pink colour as a result of hematite staining. Thus there are some difficulties attending the identification of these graptolites and this we have tried to reflect in the systematics section below.

PROBLEM PRESERVATION: POSSIBLE SOFT TISSUE

There is one interesting problem of a rather striking preservation (Fig. 2) concerning rings of hematite surrounding the graptolites. Of the hundreds of graptolites collected only nine or ten display this feature, some very strikingly. This preservation may represent soft tissue, not necessarily graptolitic, or it is more likely hematite staining, part of the overall process of preservation of the fauna. The phenomenon is two dimensional, restricted to bedding planes.

The hematite rings, or "bubbles" affected only the biserial graptolites, *Orthograptus calcaratus* s.l. and *Climograptus caudatus*. Several of the rings have an internal structure (Fig. 2) and occasionally the rings appear on the bedding plane unconnected with a graptolite. Other red stainings have a patchy, blob-like, or ring-like arrangement and these are unequivocally secondary hematitic staining of the sediment.

The most striking specimen is of *C. caudatus* (Fig. 2) which has two ring-like structures from about the 15th to the 30th thecal pair. The uppermost, larger circular body has about 40 radiating lines, looking like septae, each connected by short bars. However, under high magnification this is a more patchy structure – vesicular almost – than rigidly radiating (see interpretation in Fig. 2a). The lower, smaller circular area shows the same structures less well. Surrounding both circular areas, but not separating them, is a thick, red, hematitic band followed on the outside by an apparently vesicular layer. A small circular structure to one side of the graptolite shows the same features, and may be associated with graptolitic fragments or a smaller specimen of biserial graptolite. The specimen of *C. caudatus* is itself preserved in hematite and is possibly a scalariform view. It extends beyond the uppermost circular structure for some further 13 mm, beyond which is a slightly expanded virgula for 4 mm before the end of the slab. The preservation of the graptolites as a whole is poor with little except the virgella and its tube-like structure visible.

Other specimens do not show the above detail, but do show circular structures "attached" to specimens of *O. calcaratus* s.l. that are also stained/preserved in hematite. In some the colour of the ring-like structures is a yellow-orange, suggesting alteration to goethite. It is difficult to decide whether such structures are organic or not. If they eventually prove to be organic then they could be algal or coelenterate in nature. The only previously-known graptolite soft parts are those recorded by Kozlowski (1949) (eggs and embryos), Bulman and Rickards (1966) (embryos), Rickards and Stait (1984) (zooids), Crowther et al. (1987) (cellular tissue), and the work of Bjerreskov (1987) on pyritisation features possibly representing soft parts. Loydell et al. (2004) also describes soft tissue within the thecal tubes.

AGE OF FAUNA

Table 1 gives the global range of the identified graptolites. It is clear that the most probable horizon is Eastonian and perhaps Eastonian 2 and 3: that is, in global graptolite terms, the upper half of the *clingani* Biozone, *(caudatus* level), *morrisi* Biozone, and *linearis* Biozone. The most likely level, which we justify below, is the *caudatus/morrisi* boundary. Much of the 'wooliness' in this age attribution is due to the difficult preservation of the fauna and consequent difficulties of identification. We feel certain that some smaller species have been missed – there are, for example, small specimens we have provisionally labelled as *Cryptograptus*, and other climacograptids with proximal spines may occur.

There are a few anomalies in our identifications but these do not affect the overall judgement on the age of the fauna. The most obvious anomaly is our identification of a few specimens of ?*Climacograptus uncinatus,* normally considered a Bolindian species. We may have accidentally collected these from a loose block that came from a different part of the section; certainly the rock type is slightly different in its preservation. But if the identifications are correct it does suggest the presence of Bolindian strata nearby. There is a great deal of poor exposure in the region, as well as the quarry itself, from which we have not successfully collected. *Orthograptus quadrimucronatus quadrimucronatus* has been recorded from the Bolindian in Australia (see VandenBerg and Cooper 1992) but is much more common, globally, as shown in Table 1.

Climacograptus caudatus Lapworth has been identified with certainty and is recorded in Australia from Gisbornian 2 to Eastonian 2, but not higher. Elsewhere it occurs in the *caudatus* and *morrisi* biozones, roughly equivalent to the upper part of Eastonian 1 and Eastonian 2. The similar species *C. tubuliferus* occurs in Eastonian 3 and 4 and ranges into the Bolindian in Australia, but elsewhere occurs a little earlier, in the *morrisi* Biozone, thus overlapping slightly with *C. caudatus* (see Williams 1982, p. 246). The occurrence of these two forms together strongly suggests an age for the fauna of around the *caudatus/ morrisi* boundary, that is Eastonian 2.

There seems little in the remaining fauna that conflicts with the age attribution to Eastonian 2, apart from the examples mentioned above. The occurrence of *Orthograptus amplexicaulis intermedius* does reach the level of the *clingani* Biozone on previous records, but not the upper parts of that biozone: given the difficulties of distinguishing subspecies of *O. amplexicaulis* pending the radical revision needed for that species group, we cannot at present place much weight on the known range of *O. a. intermedius*.

Some small specimens preserved in bedding planes covered in graptolite debris may be referable to the genus *Cryptograptus*. Whilst generally considered as ranging into the low *clingani* Biozone, in Australia the genus reaches Eastonian 3 (VandenBerg and Cooper 1992) roughly the equivalent of the *linearis* Biozone. There is also a considerable number of climacograptid specimens that we have been unable to identify with certainty. They may be either early growth stages of *C. caudatus* or ones in which the tubular growth along the virgella has not occurred; or they may be referable to another species such as *C. styloideus,* which they generally resemble except in the absence of the distal nemal vane.

Finally there is a problem, it seems to us, in distinguishing *Climacograptus wilsoni* from *C. tubuliferus*; we have opted for the latter because the proximal thecae in our material show no signs of spines. Therefore we consider the most likely stratigraphic level represented by this assemblage is either the *caudatus* Biozone or the *morrisi* Biozone, or some horizon close to the boundary of the two, and to be unequivocally Eastonian.

SYSTEMATICS

NOTE: FIGURES 3-9 ARE AT THE END OF THE TEXT

Class Graptolithina Bronn 1849
Order Graptoloidea Lapworth 1875
Family Nemograptidae Lapworth (ex Hopkinson ms) 1873
Genus *Leptograptus* Lapworth 1873

Type species (by original designation) *Graptolithus flaccidus* Hall 1865.
Diagnosis Biramous, occasionally multiramous stipes, slender, flexed, often slightly reclined, with simple, long, low-angled thecae mostly without spines.

Leptograptus flaccidus (Hall, 1865) cf. *macer* Elles and Wood 1903
Figures 3a-e

cf.
1903 *Leptograptus flaccidus* var. *macer* var. nov.; Elles and Wood, pp. 110-111, pl. 15, figs 2a-i.
1934 *Leptograptus flaccidus* Hall var. *macer* Elles and Wood 1903; Ruedemann and Decker, p. 306, pl. 40, figs 5-6.
?1963 *Leptograptus* cf. *L. flaccidus* var. *macer* Elles and Wood 1903; Ross and Berry, p. 101, pl. 6, fig. 1.
1982 *Leptograptus flaccidus macer* Elles and Wood 1903; Williams, pp. 233, 236, figs 4a-e.

Lectotype Only relatively recently proposed by Williams (1982 p. 233) BU1377 figures by Elles and Wood (1903, plate 15, fig. 2e).
Material About ten specimens and numerous fragments, probably referable to this species.
Diagnosis Rhabdosome with a proximal dorsoventral width of 0.25-0.35 mm more distally 0.60 mm; variously gently flexed, but usually gently declined proximally and reclined or reflexed distally; thecal spacing 6-9 in 10 mm proximally and 8-9 in 10 mm distally.
Description The rhabdosome is variously flexed, in some specimens very gently declined or horizontal initially, becoming gently reclined or reflexed distally. A few specimens show greater curvature distally and the two stipes may have different curvature. It is uncertain how much of this variation is a result of diagenetic flattening. The sicula is often conspicuous but only a millimetre or so is preserved in the best specimens; it could be much longer because many of the siculae are clearly broken (e.g. Figs 3a, d, e). The apparent prothecal curvature seen in some specimens (e.g. Fig. 3b) does not seem to be real prothecal folding and may be a reflection of difficult preservation. The thecae are simple tubes with seemingly quite denticulate apertures in places perhaps reflecting a slight apertural expansion. The virgella is a short, conspicuous spine (see Figs 3b, c).
Remarks These specimens closely resemble *L. flaccidus macer* as described by Elles and Wood (1903) and Williams (1982) but have even lower thecal spacing proximally. Elles and Wood (1903) do give a thecal spacing of 6 in 10 mm, but this is for distal thecae; Williams (1982) also gives a reduction in the distal figure (9 in 10 proximally and 8 in 10 distally). The reverse is true in the Michelago specimens. Otherwise this material is very close to previous descriptions. *L. flaccidus* cf. *macer* differs from *L. eastonensis* in having slightly more robust stipes, in having a lower thecal spacing (10-11 in 10 mm given by Keble and Harris 1925, p. 514): Keble and Harris (1925) comment that *L. flaccidus macer* is the closest species to *L. eastonensis*. *L. flaccidus subjectus* has strongly reclined stipes in the proximal region, which later become reflexed: it otherwise resembles *L. flaccidus flaccidus* and is more robust than *L. flaccidus arcuatus* and *L. capillaris* which

have greatly flexed stipes, unlike *L. flaccidus* cf. *macer*, whilst the former is more robust. *L. flaccidus macilentus* has more rigid stipes and is more robust also. The remaining leptograptids described by Elles and Wood (1903) namely *L. validus, L. grandis, L. latus* and *L. ascendens* are all either more robust, have different thecal spacing, or both. However, it must be said that leptograptids of the *L. flaccidus* group do seem to us to show such variation as to suggest that some of the subspecies may be unrecognisable: further work on the group is necessary. Neither *L. flaccidus macer* nor *L. flaccidus spinifer* (see below) have been previously recorded from Australia. VandenBerg and Cooper (1992) list *L. capillaris, L. eastonensis,* and *L. flaccidus arcuatus*, which we have commented upon. Some slender dicellograptids have not dissimilar rhabdosomal proportions, but thecae are more complicated and the stipes ususally reclined not declined or deflexed.

Leptograptus ?flaccidus spinifer Elles and Wood (1903)
Figures 3f-i

?1903 *Leptograptus flaccidus* var. *spinifer* var. nov; Elles and Wood.

Holotype BU1037, figured by Elles and Wood (1903) plate 14, fig. 2a.
Material Three specimens, all figured herein.
Description The sicula is well-preserved 1.50-2.00 mm long and has a short nema and a conspicuous if short virgella (Fig. 3g). The virgella is deflected back across the sicular aperture. The origin and early growth of $th1^1$ and $th1^2$ is not clear but both are prominently spined: either a subapertural spine or strong denticulation, probably the latter. Subsequent thecae have no spines, are low angled (5°-10°) and have apparently simple apertures. Thecal overlap is low and thecal spacing 7-8 in 10 mm. Dorsoventral width proximally, excluding denticles, is about 0.30 – 0.40 mm and distally may reach 0.60 mm with a thecal spacing there of 9 in 10 mm.
Remarks There is a superficial resemblance to the proximal ends of some spinose dicellograptid species, but the thecae of this form are elongate, apparently simple, and low angled. Only the first two thecae are spinose/denticulate. This form has not previously been recorded from Australia: VandenBerg and Cooper (1992) record only the subspecies *L. f. arcuatus*. The closest dicellograptid is probably *D. forchhammeri* but this does have slightly introverted thecae and a higher thecal spacing value (9-12 cf. 7-8 in 10 mm).

Family Dicranograptidae Lapworth 1873
Genus *Dicellograptus* Hopkinson 1871

Type Species Subsequently designated Gurley (1896), *Didymograpsus elegans* Carruthers 1868.
Diagnosis Rhabdosome of two reclined uniserial stipes, straight or curved usually symmetrically: thecae almost simple to strongly introverted, mostly with prothecal folds proximally; variously spined, especially proximal thecae.

Dicellograptus morrisi Hopkinson 1871
Figures 4a-c

?1867 *Didymograpsus flaccidus* Hall; Nicholson, pp. 110-111, pl. 7, figs 1-3.
1868 *Didymograpsus elegans* Carruthers; Carruthers (pars) pl. 5, figs 8b, c (*non* figs 8a, d = *D. elegans* sensu stricto).
1871 *Dicellograpsus morrisi* sp. nov.; Hopkinson, p. 5, pl. 1, figs 2a-h.
1876 *Dicellograptus morrisi* Hopkinson; Lapworth, pl. 4, fig. 85.
1877 *Dicellograptus morrisi* Hopkinson; Lapworth, pl. 7, fig. 6.
1904 *Dicellograptus morrisi* Hopkinson; Elles & Wood, pp. 155-157, pl. 21, figs 6a-d, text-figs 98a-e.
1904 *Dicellograptus pumilus* Lapworth: Elles & Wood (pars), pl. 21, fig. 3c, (*non* p. 149, pl. 21, figs 3a, b, d-f = *D. pumilus* sensu stricto).
1963 *Dicellograptus morrisi* Hopkinson; Skoglund, pp. 31-32, pl. 1, figs 1, 2.
1970 *Dicellograptus morrisi* Hopkinson; Toghill, pp. 17-18, pl. 7, figs 1-4, text-figs 4d-f.
1976 *Dicellograptus morrisi* Hopkinson; Erdtmann, pp. 92-93, pl. 5, figs L/2b, M/6a, pl. 11, fig. K/2b, pl. 12, fig. K/4.
1982 *Dicellograptus morrisi* Hopkinson; Williams, pp. 238-239, figs 7e, f, 8a-c.
?1983 *Dicellograptus morrisi* Hopkinson; Williams & Bruton, pp. 169-170, figs 10D, 14A-E.
2002 *Dicellograptus morrisi* Hopkinson, 1871; Rickards, p. 4, figs 4A-D.

Type specimens Not yet designated.
Material About thirty specimens including some fragmentary uniserial stipes probably belonging to this species.
Diagnosis Stipes more than 80 mm long widening rapidly from 0.50-0.60 mm proximally to 1.2 mm distally. Axial angle from 30°-55°, axil itself slightly rounded. Thecae number 11-13 in 10 mm proximally, with curved supragenicular walls and sub-apertural

spines at least for the first nine thecae in each stipe. More distally the thecal spacing figure falls to 9-11 in 10 mm. The proximal dorsoventral width is 0.50 mm and more distally reaches 1.20-1.30 mm.

Description The complete rhabdosome is very large with stipes in excess of 70 mm. Some of the stipes are almost straight but mostly they have a gentle, ventral, distal curvature with suggestions of an equally gently spiral growth. There are a few distal fragments that reach 1.40-1.50 mm but it is uncertain whether these are referable to *D. morrisi* or not: they may be very distal fragments of very large specimens, or they may represent a second species for which we have no proximal region.

Remarks Our material supports the description of Skoglund (1963) and Rickards (2002) which gave up to eleven and eight spinose thecae respectively. In all other respects they closely agree with much of the previously described material. *Dicellograptus morrisi* has not previously been recorded from Australia.

Dicellograptus cf. *caduceus* Lapworth 1876
Figures 4d, 5a, b

1876 *Dicellograptus caduceus* Lapworth; Lapworth, pp. 141-2, pl. 7, fig. 3.
1904 *Dicellograptus caduceus* Lapworth; Elles and Wood, pp. 161-3, pl. 23, figs 4a-c, text-figs 102 a-c.

Type specimens Not yet identified.

Material About 60 specimens, some slabs with up to 10 per slab.

Diagnosis Spirally coiled stipes crossing at least twice, from a proximal region slightly rectangular and lacking, as a rule, a preserved sicula. Proximal dorsoventral width 0.40-0.50 mm, distally up to 0.70-0.80 mm; proximal thecal spacing 12-14 in 10 mm, distally about 10-11 in 10 mm.

Description The only specimen with a sicula preserved (Fig. 5b) shows a length of 1.30 mm with no attached nema. The sicula is midway between the two stipes. Early thecal development has not been seen but $th1^1$ and $th1^2$ have short spines as a rule, occasionally well-developed (Fig. 5a). Some later thecae may also have short and inconspicuous spines. The coiled stipes are conspicuous, the first crossing of stipes being at about 15-18 mm from the sicula, the maximum distance between the stipes, in the first loop, being a little under 10 mm. Two loops are common in this material, and possible three loops in some cases. Loops are similar in dimension whether the first or the third.

Remarks This form seems to differ from the original descriptions in that the stipes distally seem less than 1 mm in our material. Some of the specimens figured by Elles and Wood (1903, pl. 23) are also less than 1 mm and where they reach 1 mm may be tectonically widened. The loops seem more variable in the original material and the first loop smaller.

What is surprising, in the descriptions of a similarly enrolled species, *D. complexus,* is that neither Davies (1929, pp 3-4) nor Williams (1983, pp. 36-7) who revised the species, discuss *D. caduceus* at all. Yet the two forms are very similar in dimensions and appearance, although *D. complexus* is restricted to the *anceps* Biozone and *D. caduceus* to the *morrisi* Biozone (Eastonian 2) and, in Australia, Eastonian 3-4. The loops of *D. complexus* are smaller and tighter than in our specimens of *D.* cf. *caduceus* and Williams (1983, p. 36) implies, but does not state specifically, that *D. complexus* is distinguished from *D. caduceus* in that the former has left-handed torsion of the stipes. That feature is uncertain in our material, but may be right-handed. *Dicellograptus complexus* has not been recorded from Australia; *D. caduceus* has (see VandenBerg and Cooper, 1992) but the species, considered globally is rarely recorded. It may be that further research will recognise more variation and more species.

Dicellograptus sp.
Figures 5c, d

Material A single specimen, AMF 114903.

Description A conspicuously robust rhabdosome proximally with very large proximal spines positioned at 90° to each other; the longer spine is 8.25 mm long. Both spines may be incomplete as seen, and at their bases are about 0.50 mm wide. Approximately 0.75 mm of sicula is faintly visible but whether this is the real length is unclear. A virgella has not been identified. If the apex of the sicula is positioned as indicated the total length of the sicula could be around 1 mm if the apertural region is obscured in this specimen. There is a web of material spanning the two stipes that helps obscure the proximal region. The stipes diverge at 50° and initially have a dorsoventral width of 0.50 mm or a little more but reach 1.0 mm after only eight thecae or so and have a thecal spacing of 13 in 10 mm. We have one distal dicellograptid fragment (Fig. 5d) possibly referable to this form, with a dorsoventral width of 2 mm and a thecal spacing of 9-10 in 10 mm.

Remarks *Dicellograptus* sp. is remarkably similar in overall appearance to *D. ornatus* Elles and Wood (1904) but is a much larger and more robust form with longer, broader spines. Whilst the proximal end template is very similar, as well as the thecal spacing, the sicula is smaller and the stipes rapidly become more robust. Early growth stages of *Dicellograptus* sp. would have to be at least twice the size as comparable stages of *D. ornatus.*

Family Diplograptidae Lapworth 1873
Genus *Climacograptus* Hall 1865

Type species *Graptolithus bicornis* Hall (1847) by original designation.
Remarks Because of the general nature of the preservation of this material we have adopted a rather conservative classification of *Climacograptus* which contrasts slightly with that of VandenBerg and Cooper (1992).

Climacograptus caudatus Lapworth 1876
Figures 6a-d

1876 *Climacograptus caudatus* sp. nov.; Lapworth, pl. 2, fig. 48.
1877 *Climacograptus scalaris* var. *caudatus* Lapworth; Lapworth, pl. 6, fig. 34.
1906 *Climacograptus caudatus* Lapworth; Elles & Wood, pp. 202-203, pl. 27, figs 7a-e, text-figs 133a-d.
1908 *Climacograptus caudatus* Lapworth; Ruedemann, pp. 438-439, pl. 28, figs 17-18, text-fig 405.
?1913 *Climacograptus caudatus* Lapworth; Hadding, pp. 49-50, pl. 3, figs 18-19, text-fig. 19.
?1934 *Climacograptus caudatus* Lapworth; Ruedemann & Decker, p. 319, pl. 43, figs 1-1a.
1947 *Climacograptus caudatus* Lapworth; Ruedemann (pars), p. 424, pl. 72, figs 57-65 (*non* pl. 71, figs 51-52).
?1955 *Climacograptus caudatus* Lapworth; Harris & Thomas, pp. 38-39, pl. 1, figs 4-6.
1971 *Climacograptus caudatus* Lapworth; Strachan, p. 32.
1981 *Climacograptus? caudatus* Lapworth 1876; Williams, pp. 135-6, pl. 33, figs 1-6, 3 unnumbered text-figs.
1989 *Ensigraptus caudatus* (Lapworth 1876); Riva and Kettner, p. 89.
1990 Climacograptus caudatus VandenBerg, fig. 1.
1992 *Ensigraptus caudatus* (Lapworth); VandenBerg and Cooper, pp. 46, 48, 81, fig. 9A.
2002 *Ensigraptus caudatus* (Lapworth); VandenBerg, p. 45, fig. 5.1.4/11.

Type specimen According to Strachan (1971) the type specimen has not been traced.

Material At least 50 specimens, possibly more (see under Remarks).
Diagnosis *Climacograptus* lacking proximal thecal spines and with characteristic proximal growth of a virgellate or siculate structure (= parasicula of VandenBerg, 1990) and distal growth of a moderately robust, long virgula; rhabdosome with proximal dorsoventral width of 0.75-1.00 mm and a distal dorsoventral width of up to 2.5 mm; proximal thecal spacing 12-13 in 10 mm, distal thecal spacing 9-11 in 10 mm; distal thecae with outward-sloping supragenicular wall.
Description Few certain early growth stages have been identified, almost certainly because of preservational difficulties, but Fig. 6c is of an early growth stage with virgula and virgella preserved, the latter with traces of the typical process that grows along the virgella. The nature of this process cannot be seen in this material. In this early growth stage $th1^1$ seems unusually prominent as it does in the specimen illustrated as Fig. 6c; this feature has not been seen on any other specimens, all of which seem to have typical climacograptid thecae numbering 12-13 in 10 mm. In a few specimens (Fig. 6a) the supragenicular wall seems inclined outwards slightly as it often does more commonly in distal thecae. Whether this is real or a preservational feature is uncertain, but it has been commented upon by other workers (see Remarks). The virgella grows very long, possibly up to 10 mm and in mature specimens the characteristic virgellate growth may reach 5 mm. The virgula is always long, up to 15 mm, and fairly robust without being dramatically expended (Fig. 6d; and see following description).
Remarks VandenBerg (2002) gives a range of Eastonian 1 and 2 for this species in Victorian strata, although VandenBerg and Cooper (1992) give Gisbornian 2 to Eastonian 2 as the Australian range; this latter is in accord with the global range (Table 1). Williams (1981) was the first to draw attention to the apparently orthograptid/glyptograptid distal thecae of *C. caudatus* and hence questioned the generic attribution, although he abandoned this later (Williams 1994). It seems to us that many Ordovician climacograptids have gently outward-sloping supragenicular walls and this effects a contrast with the largely Silurian genus *Normalograptus.* Subsequently VandenBerg (2002) along with other workers recognised *C. caudatus* as the type of *Ensigraptus* (Riva and Kettner 1989) on the grounds that the early development was slightly more primitive than otherwise similar climacograptids. We cannot comment on that from this material: it is possible that the slightly conspicuous appearance of $th1^1$ in two specimens, referred to above, reflects the tendency

of that thecae to grow downwards and outwards as described by Riva and Kettner 1989.

In addition to this considerable number of specimens attributed without doubt to *C. caudatus* we have a large number of climacograptids of similar dimensions yet lacking the pronounced virgella, the parasicula, or the robust virgula (Figs 7a, b). These could be specimens of *C. caudatus* in which the robust virgella and virgula have not developed; or they could be referred to *C. tubuliferus* (see next description) in which the expanded virgular vane had not yet developed; or they could be part of a plexus marking a possible evolutionary transition from *C. caudatus* to *C. tubuliferus* (see Rickards et al. 2001). Similar forms to these, lacking a robust virgella or expanded virgules, may have been previously identified as *C. pulchellus* (Hadding 1915) (see Rickards et al. 2001 p. 79, fig. 10B). It is a pity that the preservational state of the Michelago assemblage does not allow pursuance of these questions.

Climacograptus tubuliferus Lapworth 1876
Figures 6e-h

1876 *Climacograptus tubuliferus* Lapworth; Lapworth, pl. 2, fig. 49.
1877 *Climacograptus scalaris* var. *tubuliferus* Lapworth; Lapworth, pl. 6, fig. 33.
1902 *Climacograptus tubuliferus* Lapworth; Hall, p. 55, pl. 13, fig. 5, pl. 14, fig. 4.
1906 *Climacograptus tubuliferus* Lapworth; Elles & Wood, pp. 203-204, pl. 27, figs 8a-d, text-figs 134a-c.
1947 *Climacograptus tubuliferus* Lapworth; Ruedemann, p. 440, pl. 75, figs 54-56.
?1948 *Climacograptus styloideus* Lapworth; Henningsmoen, p. 404.
1955 *Climacograptus tubuliferus* Lapworth; Harris & Thomas, p. 40, pl. 1, figs 10-12.
1960 *Climacograptus tubuliferus* Lapworth; Berry, p. 85, pl. 19, fig. 5.
1963 *Climacograptus tubuliferus* Lapworth; Ross & Berry, p. 132, pl. 10, figs 1,2.
?1963 *Climacograptus styloideus* Elles & Wood; Skoglund, pp. 38-40, pl. 2, figs 1-4. pl. 3, fig. 3.
1969 *Climacograptus tubuliferus* Lapworth; Moors, pp. 268-270, figs 3a-c.
1977 *Climacograptus tubuliferus* Lapworth; Carter & Churkin, pp. 23-24, pl. 7, fig. 5.
1982 *Climacograptus tubuliferus* Lapworth; Williams, pp. 245-246, figs 11a-n.
1983 *Climacograptus tubuliferus* Lapworth; Williams & Bruton, pp. 170-172, figs 12c-e, 15a-n.
1983 *Climacograptus tubuliferus* Lapworth; Koren' and Sobolveskaya (pars), pp. 139-141, pl. 41, figs 1-3, (*non* pl. 40, figs 6-11?).
1987 *Climacograptus tubuliferus* Lapworth, 1876; Williams, p. 80, figs 4F, H, I, 6G, 7O-Q.
?1988 *Scalarigraptus tubuliferus* (Lapworth); Riva, figs 2i, j (?=Normalograptus normalis).
1989 *Normalograptus tubuliferus* (Lapworth); Riva (in Riva and Kettner), pp. 87-89, figs 10a-i, 11a-e.
1991 *Climacograptus tubuliferus* (Lapworth, 1876); Williams, pp. 593-4, pl. 1, figs 2-4, ?5, figs 8A-C.
1992 *Climacograptus tubuliferus* Lapworth; VandenBerg and Cooper, p. 81.
1992 *Normalograptus tubuliferus tubuliferus*; VandenBerg and Cooper, p. 50, fig 10A.

Type Specimens Lapworth's original specimen has not yet been recognised (Strachan, 1971, p. 35).
Material Around 40 specimens.
Diagnosis *Climacograptus* lacking proximal thecal spines but with a characteristically expanded, ?vane-like virgula, and a small virgella; thecae broadly climacograptid numbering 10-14 in 10 mm; rhabdosome proximally with dorsoventral width of 0.70-0.75 mm rising distally to 2.50 mm.
Description Some rhabdosomes have a length of 13 cm but do not exceed 2.50 mm in dorsoventral width. The vane-like structure is up to 1 mm wide and extends distally, often as much as 20 mm, and even then may be incomplete. The proximal end usually has a small virgella but in some specimens it is more robust. It does not have a parasicula. The thecae are climacograptid throughout, except for a few specimens (Fig. 6f) where the supragenicular wall does appear to be outward leaning, though this could be a preservational feature.
Remarks *C. tubuliferus* ranges from Eastonian 2 to Bolindian 1 in Australia (VandenBerg and Cooper 1992) but elsewhere has been recorded from the latest *clingani* level (Table 1). The variation referred to above has already been commented upon under "Remarks" in the preceding description.

?*Climacograptus lanceolatus* VandenBerg 1990
Figure 7g

?1990 *Climacograptus lanceolatus* sp. nov.; VandenBerg, pp. 44-49, fig. 1, figs 7A-P, 8A-C.

Remarks A single problematical specimen is undoubtedly a *Climacograptus* species with a maximum dorsoventral width of 2 mm and a thecal spacing of 8-10 in 10 mm, which agrees with the original dimensions given by VandenBerg (1990 p.47). The proximal end has two spines and the shorter of the two directed ventrally may derive from th1[1]. The longer spine, in exactly the correct disposition for *C. lanceolatus*, is possibly the virgella, though this cannot be proved. We have no other specimens of spinose climacograptids in the collection displaying these features. *C. lanceolatus* is Eastonian 1 according to VandenBerg (1990). One of the referees suggested the possibility that this form was referable to *Pseudoclimacograptus,* but it should be noted that in some views and preservations climacograptid thecae can be slit-like without being pseudoclimacograptid.

Climacograptus mohawkensis (Ruedemann 1912)
Figures 7h, i

1906 *Climacograptus minimus* (Carruthers); Elles and Wood, p. 191, pl. 27, figs 1a-g, text-figs 124a-d.
non 1868 *Diplograptus minimus* sp. nov.; (Carruthers); p. 74, pl. 5, figs 12a, b.
1912 *Diplograptus (Mesograptus) mohawkensis* sp. nov.; Ruedemann; pp. 80-2, pl. 2, figs 18, 19, text-figs 19, 20.
1947 *Diplograptus (Mesograptus) mohawkensis* Ruedemann; Ruedemann, pp. 419-20, pl. 71, figs 24-6.
1948 *Climacograptus* cf. *minimus* (Carruthers); Henningsmoen, pp. 404-5.
1960 *Climacograptus minimus* (Carruthers); Berry, p. 80, pl. 19, fig. 2.
?1963 *Climacograptus minimus* (Carruthers); Ross and Berry, pp. 125-6, pl. 8, fig. 7.
1964 *Climacograptus minimus* (Carruthers); Obut and Sobolevskaya, pp. 57-8, pl. 11, figs 8,9.
1969 *Climacograptus minimus* (Carruthers); Riva, p. 521, text-figs 3h-j.
non 1969 *Climacograptus minimus* (Carruthers); Strachan, p. 191-2, pl. 4, fig. 3, text-figs 4a.
1977 *Climacograptus mohawkensis* (Ruedemann); Walters, pp. 937-8, pl. 2, figs f, h, i.
1982 *Climacograptus mohawkensis* (Ruedemann); Williams, pp. 246-7, figs 10c-j.
2002 *Climacograptus mohawkensis* (Ruedemann 1912); Rickards, pp. 8-9, fig. 3N.

Holotype The specimen figured by Ruedemann, 1947, pl. 71, fig. 24.
Material About 20 specimens, all indifferently preserved with thecal preservation faint.
Diagnosis Small *Climacograptus* lacking proximal thecal spines but with a short, sharp virgella; proximal thecal spacing 12-16 in 10 mm, distally 11-12 in 10 mm; dorsoventral width proximally 0.65-0.90 mm and distally 1.75 mm.
Description This is a small and inconspicuous species with details of thecae difficult to ascertain: the apertures appear to be slit-like and hence difficult not only to detect, but difficult to distinguish from "pressed through" apertures in flattened specimens like these. Consequently the above thecal spacing figures must be considered approximate. The virgula is relatively long and robust, though not expanded: it is preserved in most specimens. The most distinguishing features are the parallel-sided nature of a slim rhabdosome and the slit-like apertures.

?*Climacograptus uncinatus* Keble and Harris 1934
Figures 7c, d

?1934 *Climacograptus uncinatus* sp. nov.; Keble and Harris pp. 173-4, pl. 20, figs 5a-c.
?1972 *Climacograptus uncinatus,* Keble and Harris 1934; Carter, pp. 48-9, pl. 1, figs 2-7, 10, text-figs 2J, L-O.

Type specimen A type has never been designated.
Material Only the two specimens figured.
Remarks The thecal details of this form have never been ascertained and our material does not help much. Two of the specimens, if really referable to ?*C. uncinatus,* appear to have almost orthograptid thecae, as does one of the Keble and Harris originals (1934, pl. 20, fig. 5a). The pair of proximal spines is clearest in scalariform views (Fig 7d. herein; Keble and Harris 1934, pl. 20, figs 5b, c). In our material the spines are 2.5 mm from the proximal end, but in the types they are only 1.5 mm from the proximal end. In this respect our specimens are closer to the Carter (1972) specimens from Idaho than the specimens from Victoria. The Idaho specimens are from the *linearis* Biozone (approximately Eastonian 3) and the Victorian specimens from Bolindian 1. There is also the problem of the relationship, if any, of *C*? *uncinatus* to *O. quadrimucronatus spinigerus;* whether the pair of spines in the latter species are thecal spines or divisions of the virgula is not known. The questions must be raised on to whether *uncinatus* group has a longer range than recorded previously in Australia (VandenBerg and Cooper 1992), and whether more species are involved than previously supposed. Such questions cannot be answered until better material is available.

Genus *Orthograptus* Lapworth 1873

Type species *Graptolithus quadrimucronatus* Hall, 1865, by original designation.

Diagnosis Thecae straight or with slight sigmoidal curvature, thecal spines in one (type) group, proximal thecal spines common, and large basal spines not uncommon.

Orthograptus quadrimucronatus (Hall 1865)
Figures 7e, f

1865 *Graptolithus (Diplograptus) quadrimucronatus* sp. nov.; Hall, J., p. 144, pl. 13, figs 1-10.
1876 *Diplograptus aculeatus* Lapworth; Lapworth, pl. 2, fig. 44.
1877 *Diplograptus quadrimucronatus* Hall; Lapworth, p. 133, pl. 6, fig. 20.
1906 *Diplograptus (Orthograptus) quadrimucronatus* (Hall); Hall, T.S. p. 277, pl. 34, figs 10, 11.
1907 *Diplograptus (Orthograptus) quadrimucronatus* (Hall); Elles and Wood, pp. 223-4, pl. 28, figs 1a-d, text-figs 145a-f.
1908 *Glossograptus (Orthograptus) quadrimucronatus* (Hall); Ruedemann pp. 385-92, text-fig. 336.
1915 *Diplograptus quadrimucronatus* Hall; Hadding pp. 12-3, text-figs 3a-f.
1947 *Glossograptus quadrimucronatus* (Hall); Ruedemann pp. 452-4, pl. 78, figs 1-5.
1948 Diplograptus (Orthograptus) quadrimucronatus (Hall); Henningsmoen, pp. 403-4.
1955 *Diplograptus (Orthograptus) quadrimucronatus* (Hall); Harris and Thomas. p. 37, pl. 2, figs 37.
1970 *Orthograptus quadrimucronatus* (Hall); Toghill p. 23, pl. 13, figs 10, 11.
1982 *Orthograptus quadrimucronatus* (Hall); Williams, pp. 247-248, figs 12a-12d.
1983 *Orthograptus quadrimucronatus* (J. Hall); Koren' and Sobolevskaya, pp. 152-154, pl. 45, figs 1, 2, 58.
1987 *Orthograptus quadrimucronatus* (Hall); Mitchell, text-figs 9a-d, 9f-h.
1991 *Orthograptus quadrimucronatus* (J. Hall 1865); Williams, p. 594-5, pl. 2, figs 1-4, figs 9o-q.
1992 *Orthograptus quadr. quadrimucronatus* (J. Hall); VandenBerg and Cooper, p. 82, fig. 9k.

Type specimen Not designated. Bolton (1960 p. 104) listed Geological Survey of Canada, Ottawa, GSC 1898a, GSC 1898b and GSC 1898d, from the Utica Shale east of Pointe Bleue, Lake St. John, Quebec as syntypes.

Material Only two specimens, both figured.

Diagnosis Wide rhabdosome with dorsoventral width in excess of 3 mm within 5 mm of the proximal end from a proximal dorsoventral width of 1.50 mm; thecae denticulate and spinose with clear indications of more than one spine per theca; thecal spacing about 14 in 10 mm.

Remarks The thecal apertures appear to be not quite so inturned as in the *O. calcaratus* groups (see below); but the presence of spines along the rhabdosome is sufficient to distinguish *O. quadrimucronatus* from the *O. amplexicaulis* group (see below). Specimens of *O. quadrimucronatus* are easily missed because biprofile views do not show the spines too well and in badly-preserved collections such forms could easily be grouped in with *O. calcaratus* sensu lato. The similar species *O. whitfieldi* is a much narrower species.

Orthograptus calcaratus calcaratus (Lapworth 1876)
Figures 8a, b

1876 *Diplograptus foliaceus* Murchison v. *calcaratus* Lapworth; Lapworth pl. 1, fig. 30.
1907 *Diplograptus (Orthograptus) calcaratus* Lapworth; Elles and Wood, pp. 239-241, pl. 30, figs 1a-c, text-figs 159a-c.
1960 *Orthograptus calcaratus;* Thomas; pp. 12, 19, pl. 10, fig. 132.
1992 *Orthograptus calcaratus calcaratus* (Lapworth, 1876); VandenBerg and Cooper, p. 82.
2001 *Orthograptus calcaratus calcaratus* Lapworth); Rickards et al. p. 82, figs 11H-J.

Holotype Specimen figured by Elles and Wood 1907, pl. 30, fig. 1b.

Material Numerous specimens.

Diagnosis Robust *Orthograptus* up to 35 mm long and a distal dorsoventral width of 3.20 mm; virgula robust; proximal end with three conspicuous spines: a virgella, a robust spine on $th1^1$ and a spine low on $th1^2$; thecal apertures very slightly everted proximally and more or less horizontal distally; thecal spacing 11-14 in 10 mm proximally and 8-10 in 10 mm distally; development possibly pattern G of Mitchell (1987).

Description The sicular aperture is usually visible (Fig. 8a) but it is difficult to ascertain which is $th1^1$ and which $th1^2$. If that theca to the right is $th1^1$ then the virgella is in a strange position, unless the two left hand spines are antivirgellar spines and the virgella itself is small or missing. The second alternative seems most likely, for a short virgella is visible on the counterpart in the position marked on Fig. 8a by dashed lines. Most of the specimens show only three proximal spines, including the virgella, as do the other subspecies (see below). The thecal apertures are more nearly opposite than in many biserial graptolites, and in the proximal region they are normal to the thecal tube giving a very slightly everted appearance on flattening. More distally the apertures become horizontal or slightly introverted.

Remarks *Orthograptus calcaratus calcaratus* is still a little-understood species both in terms of its development and in terms of its relationship to several described subspecies (see also Rickards et al., 2001). Because of consequential identification difficulties the known ranges of the subspecies must be considered provisional. Considered globally the type subspecies seems to range from the *clingani* Biozone to low in the *linearis* Biozone, that is from Gisbornian 2 to Eastonian 3.

Orthograptus calcaratus ?priscus (Elles and Wood 1907)
Figure 8f

?1907 *Diplograptus (Orthograptus) calcaratus* var. *?priscus* var. nov.; Elles and Wood, pp. 244-5, pl. 30, figs 6a-c, text-fig. 164.

Type specimen Not designated according to Strachan (1971).

Material A small number of specimens, including possible fragments, about 10.

Diagnosis Strikingly robust form of *O. calcaratus,* proximally with a dorsoventral width at $th1^1/th1^2$ of 1.50 mm (excluding spines) reaching 3.50 mm by the 10th thecal pair and widening distally to 4 mm; rhabdosomes several cm long; proximal thecal spines present; thecal spacing 12-7 in 10 mm.

Description The proximal end is very robust with a "square" appearance and prominent but short spines. On Fig. 8f the interrogative marks an area that may be a fragment of an adjacent graptolite: even so the thecal spine on that side of the rhabdosome may be on the third theca. The proximal ends of other specimens are less clear still. The virgula is robust and the thecal apertures horizontal to gently introverted from the start.

Remarks The main distinguishing feature of this form from the almost equally robust *O. c. acutus* is that the proximal end of the latter is less "square" and less robust. Distally there is little difference between the two. *Orthograptus calcaratus acutus* has been recorded from Australia before, unlike *O. c. priscus* (see VandenBerg and Cooper 1992), and it occurs in Gisbornian 2 and Estonian 1. *Orthograptus calcaratus priscus* is thought to be earlier, around the *gracilis* Biozone (approximately Gisbornian 1). We do wonder whether there is much difference between these two subspecies, and whether our forms, despite their very robust proximal end, might not be better identified as *O. c.?acutus.*

Orthograptus calcaratus cf. *vulgatus* (Lapworth 1875)
Figures 8c-e

cf. 1907 *Diplograptus (Orthograptus) calcaratus* var. *vulgatus* var. nov.; Elles and Wood, pp. 241-2, pl. 30, figs 5a-d, text-figs 160a-c.

cf. 1992 *Orthograptus calcaratus vulgatus* Lapworth; VandenBerg and Cooper, p. 82, fig. 8M.

Type specimen Not yet designated according to Strachan (1971).

Material Five specimens, all figured, including two early growth stages.

Diagnosis *Orthograptus calcaratus* with virgella and two small but conspicuous proximal spines on $th1^1$ and at the base of $th1^2$; proximal end dorsoventral width is 1.40 mm (excluding spines), distally reaching in excess of 2.5 mm; thecal spacing proximally 12-16 in 10 mm, distally 10 in 10 mm.

Description The virgella is short and spike-like and $th1^1$ can be seen growing down it a short distance before turning upwards and outward, making it sometimes rather conspicuous (Fig. 8c). One early growth stage (Fig. 8e) shows a sicula with a length of 2 mm. The spine on $th1^1$ is subapertural and the spine associated with $th1^2$ is either at the base of $th1^2$ or is an antivirgella spine (?one of a pair). The thecae are typical of the species as a whole and are either slightly everted in appearance or slightly introverted.

Remarks *Orthograptus calcaratus vulgatus* ranges from Gisbornian 2 to Eastonian 2 (Table 1). Our specimens do not have definite distal parts so we are unable to confirm the distal robustness given by Elles and Wood for the original material.

Orthograptus calcaratus aff. *tenuicornis* (Elles and Wood 1907)
Figures 9b, c

cf. 1907 *Diplograptus (Orthograptus) calcaratus* var. *tenuicornis,* var. nov.; Elles and Wood, pl. 30, figs 4a-c, text-figs 163a,b.

Type specimen Not yet designated according to Strachan (1971).
Material Five specimens, all figured; some possible distal fragments.
Diagnosis *Orthograptus calcaratus* with a small virgella but with two robust spines, one on $th1^1$ and one associated with $th1^2$; rhabdosomal dimensions as type subspecies; thecal spacing 8-10 in 10 mm.
Description The rhabdosome proximally is possibly a little more slender than the type subspecies in the Michelago material, having a dorsoventral width at $th1^1/th1^2$ of 0.75 -1.00 mm and a dorsoventral width of 2.10-2.20 mm after 10 mm. $Th1^1$ has a spine positioned mesially or sub-aperturally and this bends downwards after 1 mm to reach a length of up to 3.20 mm. $Th1^2$ has a similar spine associated with it, but, as in the type subspecies, its base is either in the siculate anti-virgellar position or is low down on the free ventral wall of the theca. When anti-virgellar spines occur in biserial graptolites they are usually as a pair, and this is suggested by one specimen AMF 114913, which certainly has two spines in this position.
Remarks These forms fit the original Elles and Wood (1907) material quite well, except that the spine or spines associated with $th1^2$ seem to be in a different position. The specimens figured by Elles and Wood (1907 text-fig. 163d, b) clearly have a sub-apertural or mesially-positioned spine on $th1^2$. Our forms more closely resemble the type subspecies, at least in this respect. Thomas (1960) recorded *O. c. tenuicornis* from Australia, but VandenBerg and Cooper (1992 p.82) considered it more likely to be referable to *O. c. vulgatus* and to *O. quadrimucronatus;* they regarded *O. c. tenuicornis* as very doubtful in Australian strata and specimens from Victoria they refer to *O. thorsteinssoni.* The Michelago specimens differ from *O. thorsteinssoni* in having a tiny virgella at similar growth stages and, indeed, does not grow a long and robust virgella. The general dimensions are similar but *O. calcaratus* aff. *tenuicornis* is more slender.

Orthograptus amplexicaulis pauperatus (Elles and Wood 1907)
Figures 9d, e

1907 *Diplograptus (Orthograptus) truncatus* var. *pauperatus* var. nov.; Elles & Wood, p. 237, pl. 29, figs 5a-d.
1915 *Diplograptus truncatus* Lapworth var. *pauperatus* Lapworth mscr.; Hadding, p. 15, pl. 2, figs 8-11.
1948 *Diplograptus truncatus pauperatus* Elles & Wood; Henningsmoen, p.403.
1963 *Orthograptus pauperatus* Elles & Wood; Skoglund, pp. 45-46, pl. 1, fig. 11.
1970 *Orthograptus truncatus pauperatus* Elles & Wood; Toghill, p. 24, pl. 16, figs 1,2.
1976 *Orthograptus amplexicaulis pauperatus* Elles & Wood; Erdtmann, pp. 113-114, pl. 4, fig. M/4a, b.
1982 *Orthograptus? pauperatus* Elles & Wood; Williams, p. 251, figs 14a, f, h.
1983 *Orthograptus* pauperatus Elles & Wood, 1907; Williams and Bruton, p. 181-2, figs 21P, 22A-C, 23E.

Type species Not designated according to Strachan (1971) and Williams (1983).
Material At least 50 specimens.
Diagnosis *Orthograptus amplexicaulis* with relatively short rhabdosome, up to 30 mm long and with a maximum dorsoventral width of 2 mm; thecae simple tubes, numbering 10-14 in 10 mm; $th1^1$ and $th1^2$ with short spines.
Description The sicula is faintly visible in some specimens and may have a length of about 1.50 mm. The thecal spacing is usually around 12 in 10 mm proximally but can reach 14 in 10 mm in a few specimens. Distally the spacing is consistently 10 in 10 mm. $Th1^1$ has a small mesial spine and $th1^2$ a submesial spine (but one seemingly well clear of the sicular aperture so no confusion with anti-virgellar spines arises). Thecal apertures are normal to thecal length and thecal overlap approximately one half.
Remarks *Orthograptus amplexicaulis* is considered common in Australia (VandenBerg and Cooper 1992 p. 82) but has usually been recorded as *O. truncatus.* The same authors cast doubt on previous records of the subspecies *O. a. pauperatus,* but the evidence from Michelago seems clear. The subspecies considered globally ranges from the middle of the *clingani* Biozone to the *linearis* Biozone, which is approximately Gisbornian 2 to Eastonian 3.

Orthograptus amplexicaulis intermedius (Elles and Wood 1907)
Figure 9f

1907 *Diplograptus (Orthograptus) truncatus* var. *intermedius* var. nov.; Elles and Wood, p. 236, pl. 29, figs 4a-c, text-figs 156a, b.

Type species Not yet designated according to Strachan (1971).
Material One good specimen, figured, and a few doubtful fragments.
Description The rhabdosome reaches a dorsoventral width of 2.50 mm by the 11th thecal pair and

thereafter increases very slightly to 2.70 mm. There are very long fragments of rhabdosome which may be referable to this subspecies but without proximal ends attached: these fragments have a dorsoventral width of 2.50 – 2.70 mm and a thecal spacing of 10-12 in 10 mm. The specimen illustrated herein has a proximal thecal spacing of 14 in 10 mm and a more distal one of 11-12 in 10 mm. The most striking feature of the rhabdosome is the relatively high angle of thecal inclination (50°-60° distally). Th1^1 has a sub-apertural spine and th1^2 a spine low on the free ventral wall, close to the sicula.

Remarks *Orthograptus truncatus intermedius* was recorded from Australia by Thomas (1960) but this was rejected by VandenBerg and Cooper (1992). So ours may be the first record of the form from NSW and Australia.

Genus *Glyptograptus* Lapworth 1873

Type species *Diplograpsus tamariscus* Nicholson (1868) by original designation.

Diagnosis (emended Koren' and Rickards 1996) Proximal development of *tamariscus* (I) Pattern: thecae with sigmoidal curvature varying from gentle to sharp ('climacograptid'); supragenicular wall vertical in some, to, more commonly, sloping outwards; apertures generally everted but may be horizontal; may be septate, aseptate or partially septate; thecal and sicular spinosity uncommon; nemal vanes not uncommon; sicula usually less than 2 mm long.

Glyptograptus daviesi Williams 1982
Figure 9a

1982 *Glyptograptus daviesi* sp. nov.; Williams pp. 251-2, figs 14b-d.

Holotype From the *clingani* Biozone, North Cliff trench, Dob's Linn, Southern Uplands, Scotland, figured Williams (1982) as 14c.

Material A single definite specimen and a small number of other less well-preserved specimens.

Description A diminutive *Glyptograptus* with sharp virgella and thread-like virgula and typically gently geniculate thecae numbering 15-16 in 10 mm. The free ventral wall of th1^1 is relatively short at 0.50 mm compared with that of th1^2 at 0.75 mm. The down-growing part of th1^1 is not visible. Thecal apertures are more or less normal to the thecal length. Overlap cannot be seen. The proximal dorsoventral width is 0.90 mm and by the seventh thecal pair the dorsoventral width is 1.40 mm.

Remarks The best specimen is identical to those recorded by Williams (1982) from Southern Scotland and is a first record for Australia.

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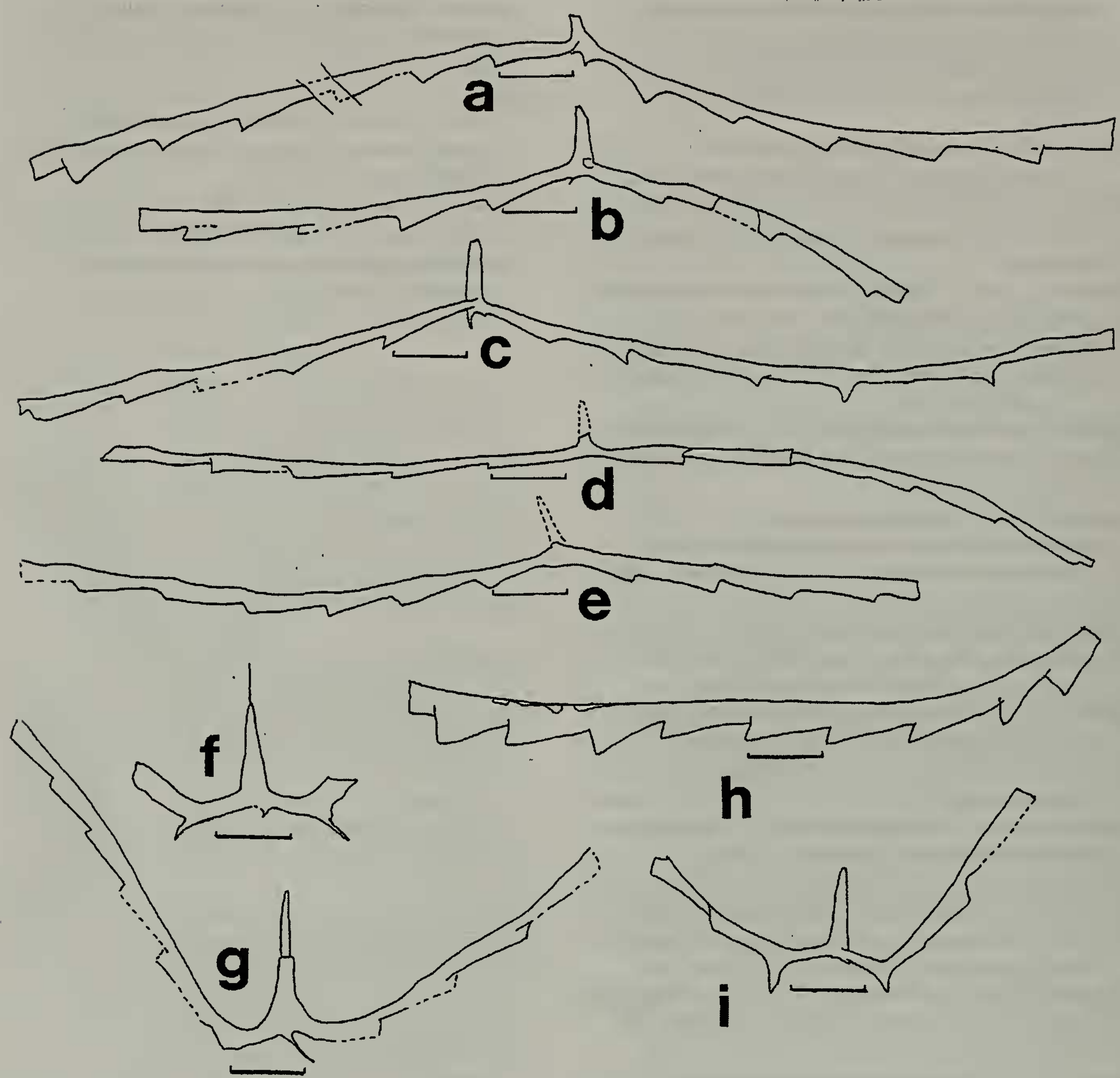

Figure 3 a-e *Leptograptus flaccidus* cf. *macer* Elles and Wood, respectively AMF114895, 114938, 114939, 114934, 114892; f-i *Leptograptus ?flaccidus spinifer* Elles and Wood, respectively AMF 114942, 114886, 114887, 114941; scale bars 1 mm.

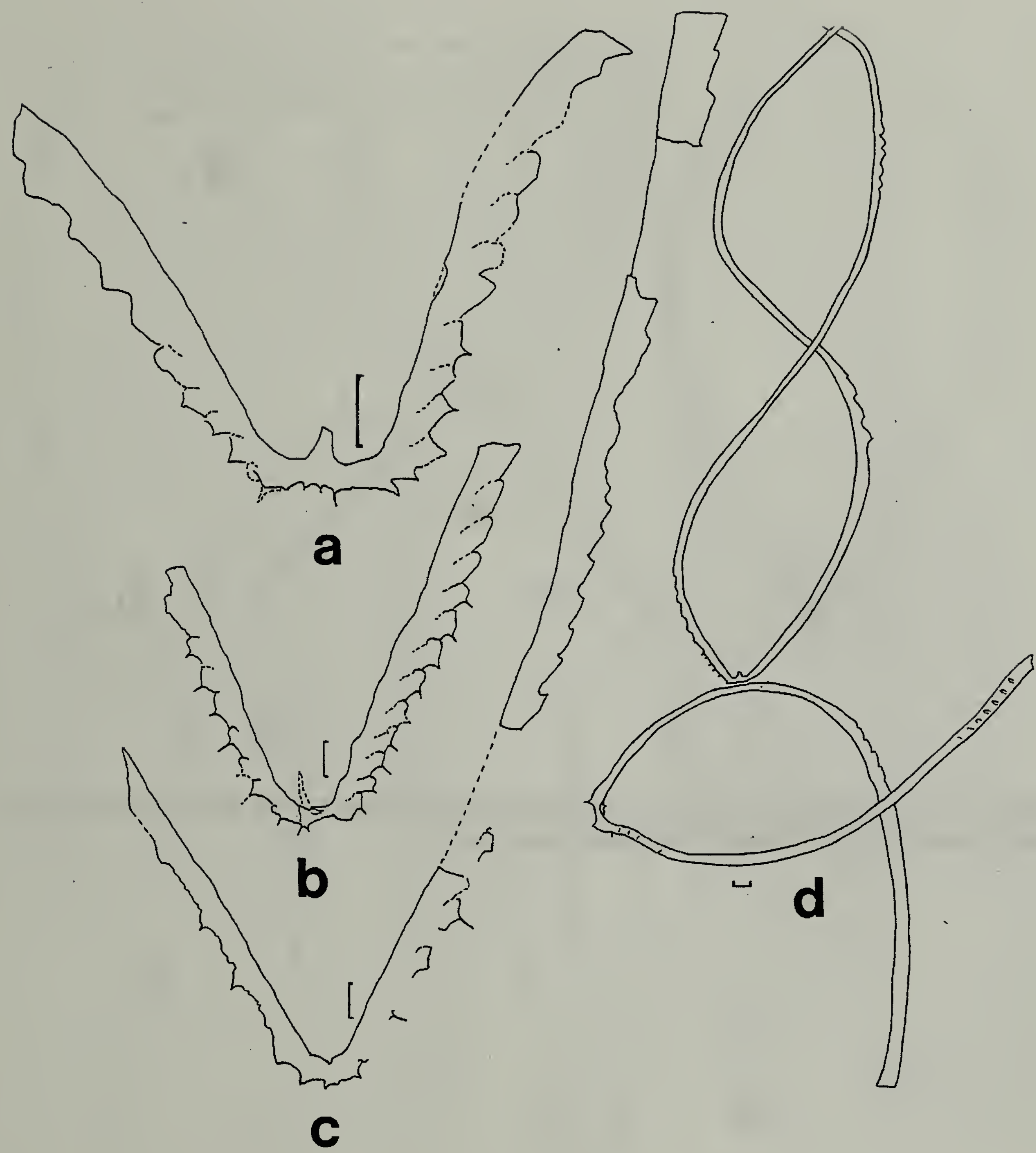

Figure 4 a-c *Dicellograptus morrisi* Hopkinson, respectively AMF 114925, 114947, 114910; d *Dicellograptus* cf. *caduceus* Lapworth, AMF 114922-3, specimens adjacent on same slab; scale bars 1 mm.

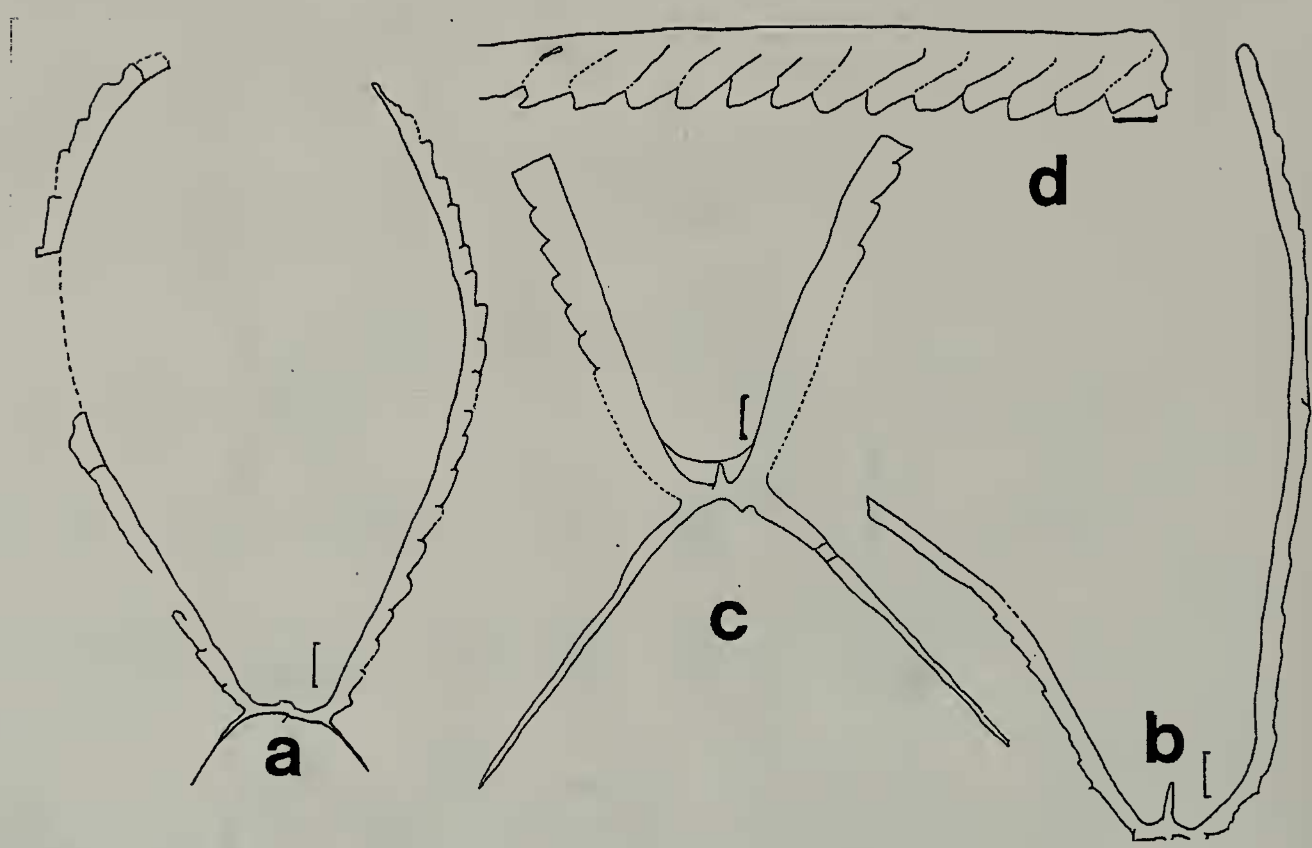

Figure 5 a, b *Dicellograptus* cf. *caduceus* Lapworth, respectively AMF 114958, 114924; c,d *Dicellograptus* sp., respectively AMF 114903, 114891; scale bars 1 mm.

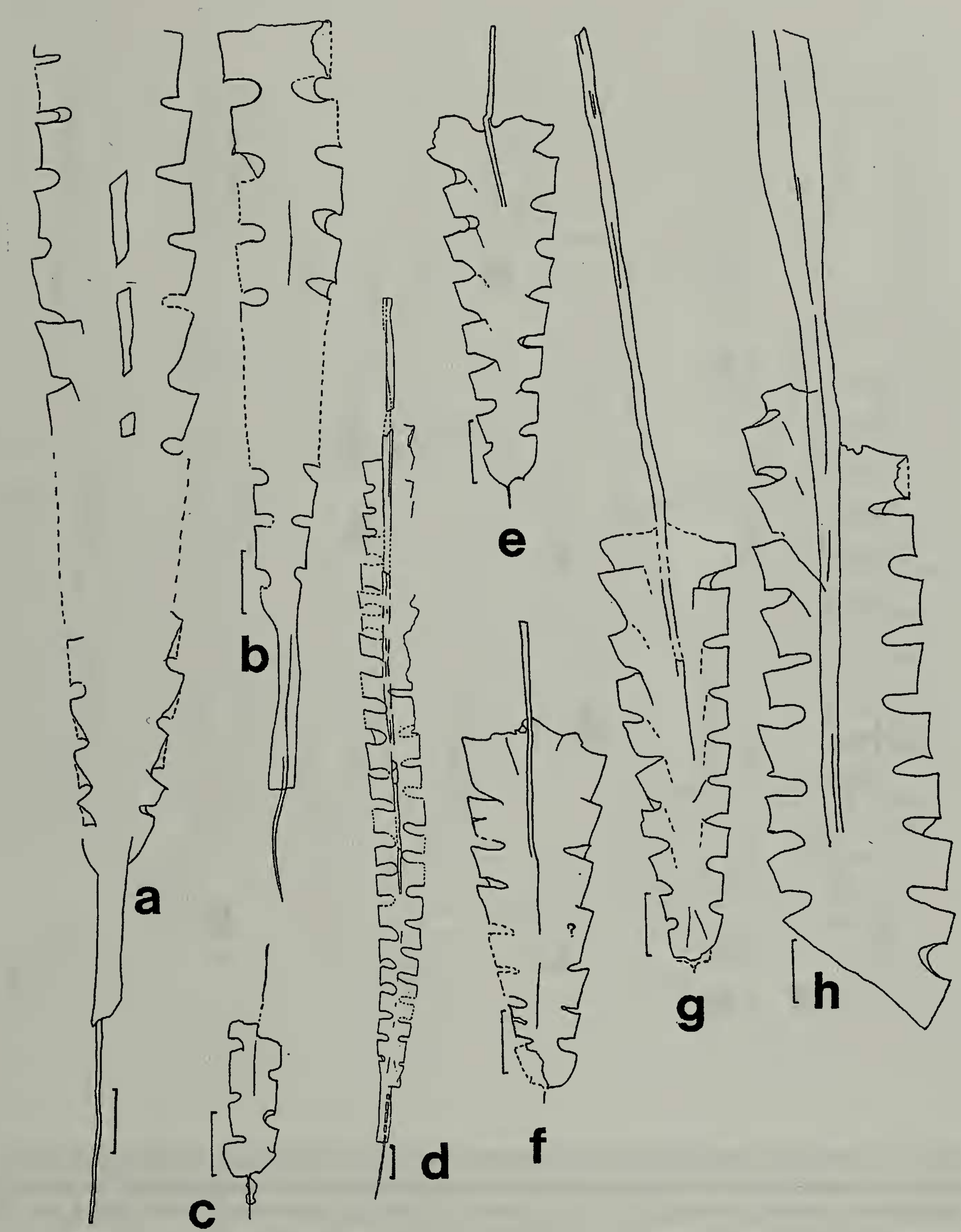

Figure 6 a-d *Climacograptus caudatus* Lapworth, respectively AMF 114904, 114906, 114949, 114905; e-h *Climacograptus tubuliferus* Lapworth, respectively AMF 114896, 114900, 114897, 114899; scale bars 1 mm.

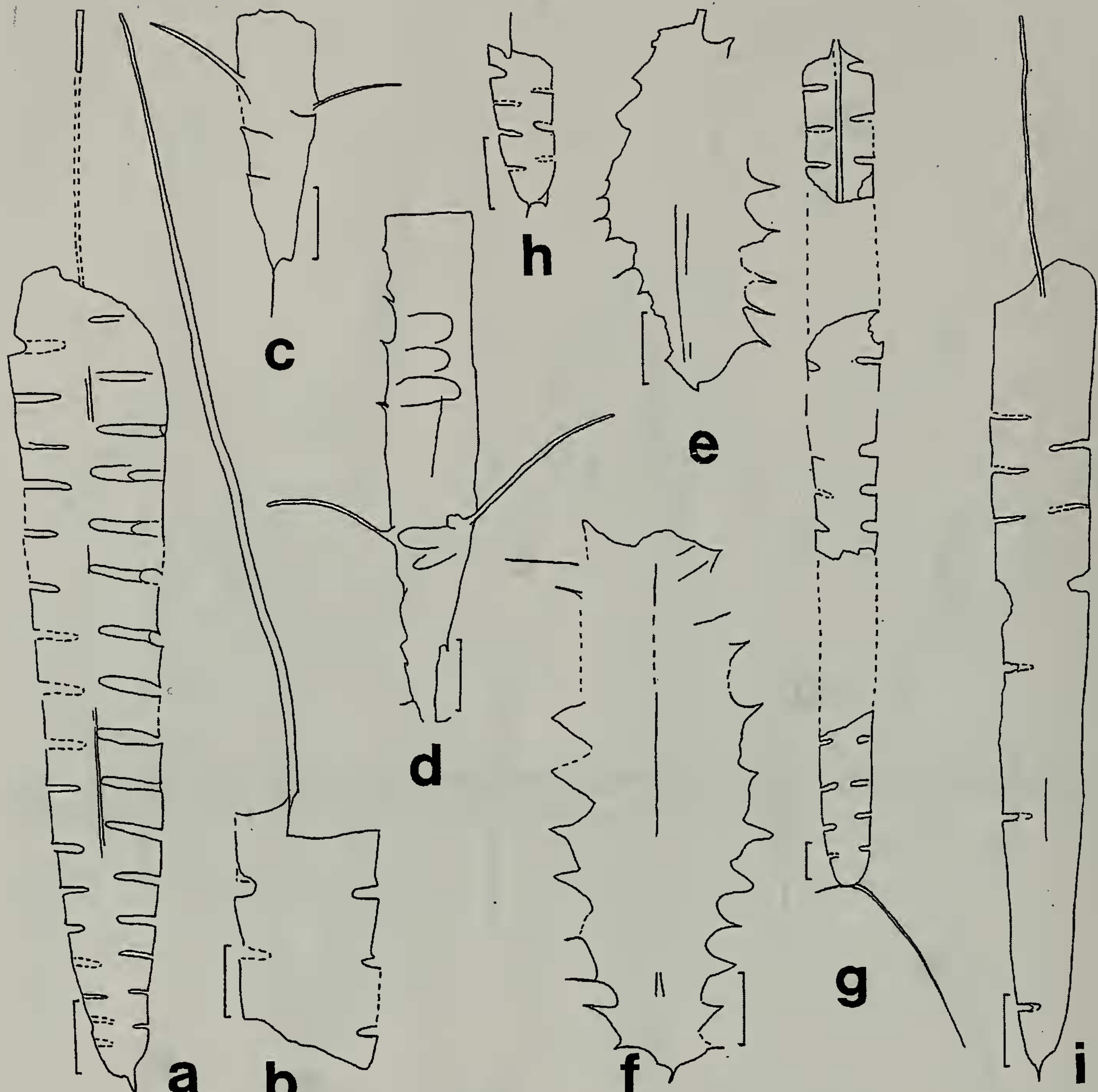

Figure 7 a, b Climacograptus sp., respectively 114952, 114919; c,d *Climacograptus*? *uncinatus* Keble and Harris, respectively AMF 114950, 114889; e,f *Orthograptus quadrimucronatus* (J. Hall), respectively AMF 114916, 114917; g ?*Climacograptus lanceolatus* VandenBerg; AMF 114959; h,i *Climacograptus mohawkensis* (Ruedemann), respectively AMF 114911, 114915; scale bars 1 mm.

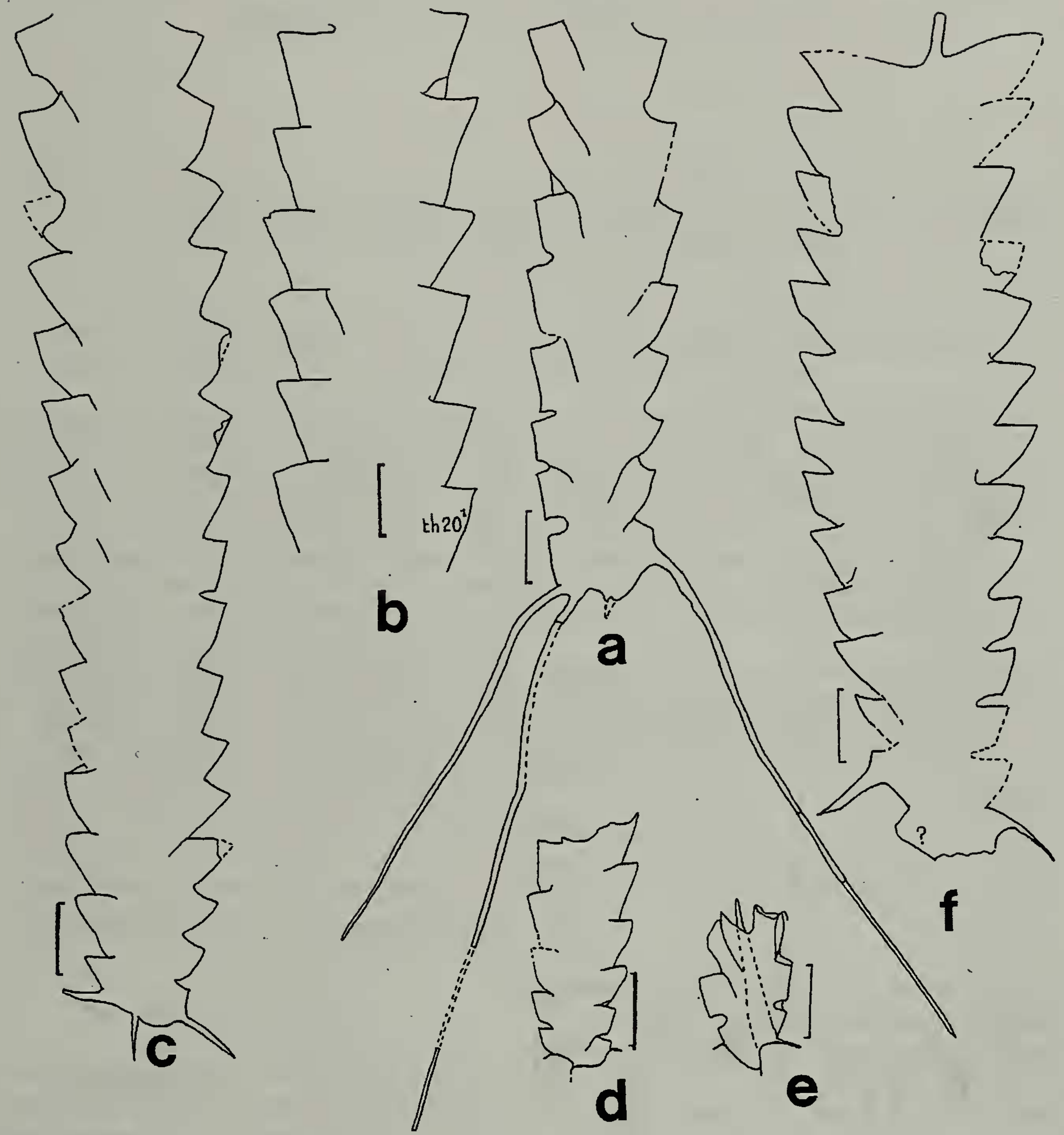

Figure 8 a,b *Orthograptus calcaratus calcaratus* (Lapworth), AMF 114920 respectively proximal and distal parts of a long specimen; c-e *Orthograptus calcaratus* cf. *vulgatus* (Lapworth), respectively AMF 114945, 114956, 114951; f *Orthograptus calcaratus* ?*priscus* (Elles and Wood), AMF 114937; scale bars 1 mm.

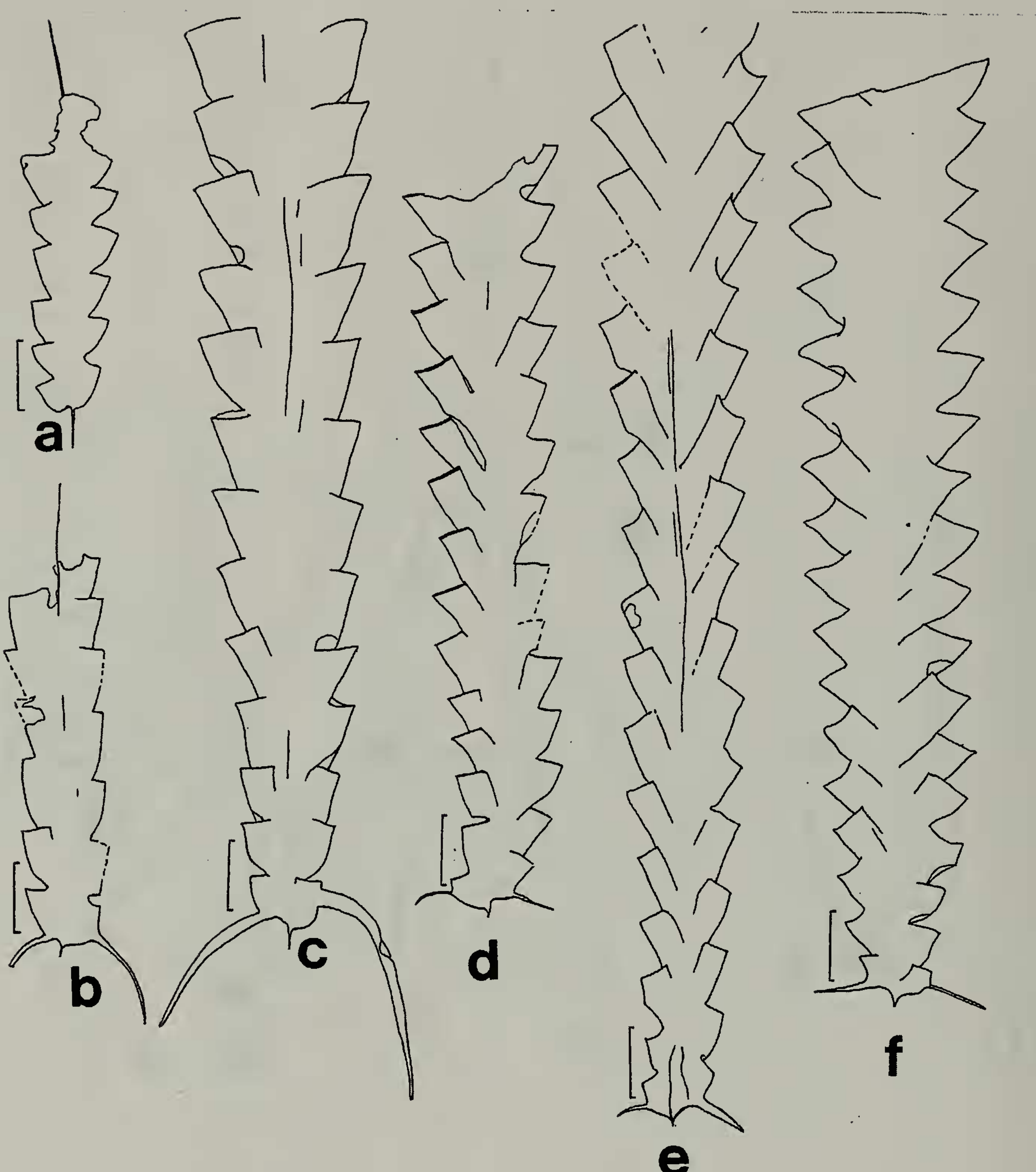

Figure 9a *Glyptograptus daviesi* Williams, AMF 114946; b,c *Orthograptus calcaratus* aff. *tenuicornis* (Elles and Wood), respectively AMF 114933, 114888; d, e *Orthograptus amplexicaulis pauperatus* (Elles and Wood), respectively AMF 114901, 114898; f *Orthograptus amplexicaulis intermedius* (Elles and Wood), AMF 114893; scale bars 1 mm.